AFRL-RI-RS-TR-2016-149

NEW FRONTIERS IN NETWORKING WITH EMPHASIS ON DEFENSE APPLICATIONS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2016

FINAL TECHNICAL REPORT

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REPORT DOCUMENTATION PAGE	*Form Approved* **OMB No. 0704-0188**

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
JUNE 2016	FINAL TECHNICAL REPORT	DEC 2014 – DEC 2015

4. TITLE AND SUBTITLE NEW FRONTIERS IN NETWORKING WITH EMPHASIS ON DEFENSE APPLICATIONS	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER FA8750-15-1-0034
	5c. PROGRAM ELEMENT NUMBER 62715E
6. AUTHOR(S) Vincent W.S. Chan	**5d. PROJECT NUMBER** RMAP
	5e. TASK NUMBER MI
	5f. WORK UNIT NUMBER T2
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Massachusetts Institute of Technology Claude E. Shannon Communications & Network Group, Research Laboratory of Electronics 77 Massachusetts Ave Cambridge, MA 02139	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory/RITE 525 Brooks Road Rome NY 13441-4505	**10. SPONSOR/MONITOR'S ACRONYM(S)** AFRL/RI
	11. SPONSOR/MONITOR'S REPORT NUMBER AFRL-RI-RS-TR-2016-149

12. DISTRIBUTION AVAILABILITY STATEMENT

Approved for Public Release; Distribution Unlimited. DARPA DISTAR CASE # 25835
Date Cleared: NA

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Future networks will increasingly become heterogeneous and networks will be much more highly tuned to achieve much better performance than current architectures (e.g. increase of ~1000 times in data rate even under extreme conditions such as high mobility). These networks will have multiple modalities (wired, wireless, satellite) with disparate channel properties, user rates that range from low to ultra-high (Tbps+) and a wide range of service requirements. Many new network problems that arise in future networks may not be served well by the ~50 year old Internet architecture even with constant evolutions. Increasingly the link layers are very dynamic in their adaptation to rapidly changing environments including both channel properties, achievable rates and offered traffic. When the networks go through a disruptive jump in rates and service quality in the future, they must be built with new innovations in network architectures to drive cost down to affordable levels. Linear extensions of old Internet packet switching architectures and techniques no longer will be the concept that can fully serve future applications. We will convene a roundtable discussion to explore the properties of emerging applications and identify new architecture techniques and constructs.

15. SUBJECT TERMS

Network Architecture Techniques, Broadband Fiber Networks, Framework for Enabling High Data Rate Transmissions, Channel Access in Dense Environments

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**HOWARD M. BEYER**
U	U	U	UU	11	**19b. TELEPHONE NUMBER** (*Include area code*) **N/A**

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1. SUMMARY: DEFENSE NETWORK NEEDS

Future networks will increasingly become heterogeneous and networks will be much more highly tuned to achieve much better performance than current architectures (e.g. increase of ~1000 times in data rate even under extreme conditions such as high mobility). These networks will have multiple modalities (wired, wireless, satellite) with disparate channel properties, user rates that range from low to ultra-high (Tbps+) and a wide range of service requirements. Many new network problems that arise in future networks may not be served well by the ~50 year old Internet architecture even with constant evolutions. Increasingly the link layers are very dynamic in their adaptation to rapidly changing environments including both channel properties, achievable rates and offered traffic. When the networks go through a disruptive jump in rates and service quality in the future, they must be built with new innovations in network architectures to drive cost down to affordable levels. Linear extensions of old Internet packet switching architectures and techniques no longer will be the concept that can fully serve future applications. We will convene a roundtable discussion to explore the properties of emerging applications and identify new architecture techniques and constructs that are based on scientific understandings and optimization of architectures.

2. INTRODUCTON

This study intended identify new network architecture techniques that are appropriate for broadband fiber networks with virtually unlimited capacities, advanced multiple antenna techniques (beyond MIMO and beam forming) and the availability of massive computing capability, e.g. at a cloud. In the wide area for fiber and satellite networks with dynamically changing links and offered traffic loads, we identified possible new solutions to large and broad granularity traffic. These techniques are needed to support new applications such as big data analytics, collaborative sensing and massive data networking in a manner that the network and applications will be aware of each other's capabilities and available resources, and adaptively and jointly optimize application performance.

3. METHODS, ASSUMPTIONS, AND PROCEDURES

The approach used to identify new techniques was to invite US network experts to participate in a two day roundtable to discuss ideas for developing the underlying "science" of future networks. The aim was to examine all valid and useful ideas for further explorations but not to force all ideas in one single coherent thrust.

On April 30 and May 1 2015, MIT hosted the roundtable.

The following people briefed the government at the roundtable:

- Vincent Chan, MIT
- Peter Steenkiste, Carnegie Mellon University
- Dipankar Raychaudhuri, WINLAB, Rutgers University
- Patrick Crowley, Department of Computer Science & Engineering, Washington University in St. Louis
- Cedric Lam, Engineering Director, Google
- Robert Doverspike, Network Evolution Strategies
- Vinod Vokkrane, University of Massachusetts – Lowell
- Loukas Paraschis, Technology Solution Architect, Cisco
- Jack Nasielski, Senior Director, Qualcomm Technologies, Inc
- Guevara Noubir, College of Computer and Information Science, Northeastern University
- Kenneth J. Hetling, Lincoln Laboratory, MIT
- Cindy Dion-Schwarz, Senior Scientist, Rand Corporation
- Jason Redi, Network and Communications Technologies, Raytheon BBN Technologies
- Donald F. Towsley, College of Information and Computer Sciences, Umass-Amherst
- Alberto Leon-Garcia, NSERC Strategic Network for Smart Applications on Virtual Infrastructures, University of Toronto
- Radia Perlman, Fellow, EMC Corporation
- Dave Oran, Fellow, Cisco Systems
- Muriel Medard, Networking Coding and Reliable Communication Group, MIT

Further information concerning this workshop can obtained at
http://newfrontiers.mit.edu/finalreport2015/New%20FrontiersApp.pdf.

Promising areas of research were identified and a set of recommendations were provided to DARPA DSO

4. RESULTS AND DISCUSSION: MAJOR CHALLENGES FACING FUTURE NETWORKS ARCHITECTURES

The project identified the following as major challenges facing future defense network architectures:

a. Fluid and rapidly changing link layers for wireless and satellite communications. This challenge will necessitate changes in protocols from Layer 1 to Layer 4. Examples are: new MAC and ARQ in Layer 1 and 2 working in conjunction with routing or network coding at Layer 3 and 4; joint optimization of throughput and quality of service involving antenna processing (beyond beam pointing, nulling and MIMO) and Layer 3 routing and Layer 4 error recovery techniques, etc. In fact the last technique may not be an option but a necessary new feature.

b. Multiple user nodes that can act cooperatively to relay information and participate in joint receptions. All or subsets of neighbors can combine resources to create links to improve the rate and quality of transmissions to third parties. The dynamic nature of the network is magnified in high frequency systems such as 60GHz where the coherence time is so short that the notion of a stable network topology no longer makes sense. One key question to address is “what is the right concept and theory for these networks to replace conventional network quasi-static topology design and routing?

c. Due to the fast dynamics and sometimes large granularity of future networks, monitoring of these networks is an important component of network management and control. Sensing and reporting full link states is nice but impractical due to the huge amount of data involved. The volume of link state data will increase by orders of magnitude and sensing and communicating them to the right entities will require very high precious data rates and moreover, network management and control systems will not be able to make timely use of these information. Compact statistical representations of parameters that largely but not fully describe the behavior of these networks must be developed and the performances of algorithms that use these parameters need to be quantified. In many cases, full sensing instrumentation of the network is impossible and the network must use adaptive learning mechanisms for assessing state and trajectories of important network parameter given only sparse sensor feedback. Users can also participate in network state sensing through its own experiences.

d. The presence of “elephants” in the network is triggered partly by big data and partly by high resolution videos. What is very apparent is that the current IP architecture will not be efficient for servicing these applications. In fact old techniques such as queueing theory cannot adequately quantify the performance of many new approaches such as scheduled flows and software defined networks that are being proposed. In optical fiber networks, the capacity per fiber exceeds 10Tbps. We have examined a new mechanism called Optical Flow Switching for transporting elephants and found even for this very limited mode of operation, good architectures with orders of magnitude rate and cost improvements are very different from the traditional packet switching paradigm. There is currently no unifying theory to find the capacity and good performing, let alone optimum, algorithms for these network services.

e. Management and control of future networks will be very different from the current quasi-static slowly adapting systems due to the fast changing environment and traffic pattern. Active stabilization of the networks is an imperative since they operate with such fast dynamics that existing slow-adaptation approaches are inefficient and even unstable. The key question to be addressed is, what is the new “control theory” for networks with: too many variables to measure and must decide which subset to monitor at each instant; noisy observed states that can be stale; operating away from equilibrium; multiple distributed control mechanisms operating at different time scales; variable feedback delays that depends on the level of congestion and external offered traffic loads; network control parameters and response functions changing based on external traffic conditions? Are there cognitive techniques and model-based control mechanisms that can dynamically track the network states and sustain optimization under these conditions?

5. CONCLUSIONS

The roundtable:

a) Reviewed the range of options available to address threats to space systems, in terms of deterring hostile actions, defeating hostile actions, and surviving hostile actions.
b) Assessed potential strategies and plans to counter such threats, including resilience, reconstitution, disaggregation, and other appropriate concepts.
c) Assessed existing and planned architectures, warfighter requirements, technology development, systems, workforce, or other factors related to addressing such threats.
d) Recommend architectures, capabilities and courses of action to address such threats and actions to address affordability, technology risk, and other potential barriers or limiting factors in implementing such courses of action.

6. ACRONYMS

AODV - Ad Hoc On-Demand Distance Vector
API - Application Program Interface
APP - Aware Application
AR - Advance Reservations
ARQ - Automatic Repeat reQuest
C2 - Command and Control
COMSEC - Communications Security
CONOPS - Concept of Operations
CPU - Central Processing Unit
COTS - Commercial Off-The-Shelf
DSA - dynamic spectrum access
DSP - Digital Signal Processor
DSR - Dynamic Source Routing
Dsware - Data Service Middleware
EEW - Electronic Warfare
FHSS - Frequency-Hopping Spread Spectrum
GPS - Global Positioning System
GUI - Graphical User Interface
HAL - Hardware Abstraction Layer
IA - Information Assurance
INFOSEC - Information Security
IP - Internet Protocol
ISR - Intelligence, Surveillance, and Reconnaissance
JSON - Java Script Object Notation
LVM - Logical Volume Management
MAC - Media Access Control
MGEN - a packet generator
MIMO - multiple-input and multiple-output
NDN - Named Data Networking
OLSR - Optimized Link State Routing Protocol
PD - Platform Dependent
PER - Packet Error Rate
PI - Platform Independent
POSIX - Portable Operating System Interface
PSD - Personal or Portable Storage Device

RLNC - random linear network coding
RR – Resource Record
SDN - Software-defined networking
SDR - Software Defined Radios
SIA - System ID Authority
SNMP - Simple Network Management Protocol
SOW - Statement of Work
SSP - State Synchronization Protocol
STP - Spanning Tree Protocol
RF - Radio Frequency
TBPS - Terabytes per second
UDP - User Datagram Protocol
VM - Virtual Machine
WAN - wide area network